E7.3 10594
CR-131910

FACILITATING THE EXPLOITATION OF ERTS-1 IMAGERY UTILIZING SNOW ENHANCEMENT TECHNIQUES

(E73-10594) FACILITATING THE EXPLOITATION OF ERTS-1 IMAGERY UTILIZING SNOW ENHANCEMENT TECHNIQUES Progress Report, 1 Sep. 1972 - 30 Apr. 1973 (Earth Satellite Corp.) 64 p HC $5.25 CSCL 05B G3/13 N73-25334 Unclas 00594

Dr. Frank J. Wobber
Director, Geosciences and
Environmental Applications Division
Earth Satellite Corporation
1747 Pennsylvania Avenue, N.W.
Washington, D.C. 20006

Mr. Kenneth R. Martin
Geographer, Geosciences and
Environmental Applications Division
Earth Satellite Corporation
1747 Pennsylvania Avenue, N.W.
Washington, D.C. 20006

Mr. Roger V. Amato
Geologist, Geosciences and
Environmental Applications Division
Earth Satellite Corporation
1747 Pennsylvania Avenue, N.W.
Washington, D.C. 20006

May 1973
Type II Progress Report For Period: September 1, 1972-April 30, 1973

Prepared for
ERTS PROGRAM OFFICE
NASA GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

Original photography may be purchased from

EARTH SATELLITE CORPORATION
(EarthSat)

1747 PENNSYLVANIA AVENUE, N.W., WASHINGTON, D. C. 20006
TELEPHONE: (202) 223-8100 TELEX: EARTHSAT64449

May 24, 1973

Mr. Fred Gordon
Technical Monitor
Goddard Space Flight Center
Code 430
Greenbelt, Maryland 20771

RE: SR #141, ERTS-1 Snow Enhancement Experiment
(Contract NAS5-21744)

Dear Mr. Gordon:

Enclosed please find a copy of the semi-annual (Type II) progress report for the ERTS Snow Enhancement Experiment. I believe that you will find it a complete and substantive account of our progress and accomplishments to date.

An ERTS photo base map of western Massachusetts will be prepared to document the detectability of fractures utilizing comparative snow-free and snow-cover imagery. I believe that you will share our interest in the development of practical illustrative ERTS products.

I look forward to meeting and working with you in the near future.

Sincerely yours,

Frank J. Wobber
Director
Geosciences and Environmental
Applications Division

Enclosure
cc: Dr. Lowman
FJW/kw

/

1. Report No. ESC 141-6	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FACILITATING THE EXPLOITATION OF ERTS-1 IMAGERY UTILIZING SNOW ENHANCEMENT TECHNIQUES		5. Report Date May, 1973 6. Performing Organization Code
7. Author(s) Dr. Frank J. Wobber Kenneth R. Martin and Roger V. Amato		8. Performing Organization Report No.
9. Performing Organization Name and Address Earth Satellite Corporation 1747 Pennsylvania Avenue Washington, D.C. 20036		10. Work Unit No. 11. Contract or Grant No. NAS5-21744 13. Type of Report and Period Covered Type II Report September, 1972 - April, 1973
12. Sponsoring Agency Name and Address ERTS Program Office Arthur Fihelly, Technical Monitor		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Snow cover in combination with low angle solar illumination has been found to provide increased tonal contrast of surface features and is useful in the detection of bedrock fractures. Identical fracture systems were not as readily detectable in the fall due to the lack of a contrasting surface medium (snow) and a relatively high sun angle. Low angle solar illumination emphasizes topographic expressions not as apparent on imagery acquired with a higher sun angle.

A strong correlation exists between the major fracture-lineament directions interpreted from multi-sensor imagery (including snow-free and snow-cover ERTS) and the strike of bedrock joints recorded in the field indicating the structural origin of interpreted fracture-lineaments.

A fracture-annotated ERTS-1 photo base map (1:250,000 scale) is being prepared for western Massachusetts. The map will document the utilization of ERTS imagery for geological analysis in comparative snow-free and snow-covered terrain.

17. Key Words (Selected by Author(s)) Snow Enhancement, Fractures, Lineaments, Remote Sensing, Snow Cover Imagery	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 63	22. Price*

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PREFACE

The objective of this ERTS investigation is to evaluate the effectiveness of snow cover (and the monitoring of progressive snow-melt and accumulation patterns) as a photogeological enhancement technique.

This report is an up-to-date review of the investigator's analysis of ERTS imagery of snow-covered terrain. It confirms the value of snow enhancement for fracture analysis and presents the initial analytical results of ERTS snow-covered imagery.

Snow cover in combination with low angle solar illumination provides increased tonal contrast of surface features and is useful in the detection of bedrock fractures. Within the New England Test Area identical fracture systems were not as readily detectable in the fall due to the lack of a contrasting surface medium (snow) and a relatively high sun angle. Low angle solar illumination emphasizes topographic expressions not as apparent on imagery acquired with a higher sun angle.

A strong correlation exists between the major fracture-lineament directions interpreted from multi-sensor imagery (including snow-free and snow-cover ERTS) and the strike of bedrock joints recorded in the field. This indicates that the interpreted fracture-lineaments were surficial expressions of bedrock structure.

Viewing techniques (e.g., additive color presentations, density slicing, use of film sandwich and Ronchi grating) currently being tested promise to supply additional enhancement to the natural enhancement provided by snow cover and low angle solar illumination. In particular, additive color has contributed information related to fracture-influenced vegetative alignments.

A fracture-annotated ERTS-1 photo base map (1:250,000 scale) is being prepared for western Massachusetts. The map will document the utilization of ERTS imagery for geological analysis in comparative snow-free and snow-covered terrain.

TABLE OF CONTENTS

	PAGE
1.0 INTRODUCTION	1
1.1 General Introduction	1
1.2 Summary of Accomplishments	1
2.0 BACKGROUND	7
2.1 Literature Review	7
2.2 Pre-ERTS Investigations	7
2.3 Concept of Snow Enhancement	8
3.0 ANALYTICAL PROCEDURES AND TECHNIQUES	10
3.1 Analysis Procedures	10
3.2 Analysis Techniques	10
3.3 Field Investigations	12
3.4 Fracture-Lineament Validation	12
3.5 Selection of Detailed Test Sites	13
4.0 MULTI-SENSOR DATA ANALYSIS OF TEST SITE #1	15
4.1 Geographic Location and Site Selection Rationale	15
4.2 General Geology	15
4.3 Field Observations	17
4.4 Multisensor Data Analysis	17
4.4.1 ERTS Imagery (Snow-Free)	18
4.4.2 ERTS Imagery (Snow-Covered)	18
4.4.3 SLAR Imagery	18
4.4.4 U.S.G.S. Aeromagnetic Maps	23

		PAGE
4.4.5	High Altitude CIR Photography (Snow Covered)	23
4.4.6	Low Altitude Color Photography (Snow Covered)	25
4.5	Results and Conclusions	25
5.0	SIGNIFICANT RESULTS	27
5.1	General Results and Findings	27
5.2	Summary of Significant Results	29
6.0	NEW TECHNOLOGY	31
7.0	PROGRAM FOR NEXT REPORTING PERIOD	31
7.1	Procedural Analysis	31
7.2	Task Summary	31
7.3	Anticipated Principal Products	32
8.0	CONCLUSIONS	33
9.0	RECOMMENDATIONS	34

APPENDICES

A. PROGRESS REPORT SUMMARY

B. TASK STATUS REPORT

C. GLOSSARY OF TERMS

D. ERTS IMAGE DESCRIPTOR FORMS

E. WORLD MINING PAPER

F. BIBLIOGRAPHY

LIST OF ILLUSTRATIONS

FIGURE		PAGE
1	New England Test Area	14
2	Geologic Map Of Great Barrington, Massachusetts Test Site With Accompanying Location Map	16
3a	ERTS MSS Image Of Snow-Free Terrain	19
3b	Fracture Annotated Image Of Snow-Free Terrain	19
4a	ERTS MSS Image Of Snow-Covered Terrain	20
4b	Fracture Annotated Image Of Snow-Covered Terrain	20
5a	Side Looking Airborne Radar (SLAR) Image	21
5b	Fracture Annotated SLAR Image	21
6a	Measurement Summary Of Fractures Interpreted from SLAR Imagery	22
6b	Measurement Summary of Fractures Interpreted From Color Infrared (CIR) Imagery	22
6c	Measurement Summary of Fractures Interpreted From ERTS Image Of Snow-Covered Terrain	22
6d	Measurement Summary Of Bedrock Joints	22
7	Aero-Magnetic Map Of Western Massachusetts	24

LIST OF TABLES

TABLE		PAGE
1	Sequential Validation System	4
2	Influence Of Snow Depth On Geological Feature Enhancement	5
3	Evaluation Of Fracture Detectability Utilizing Multispectral ERTS-1 Imagery Of Snow-Covered Terrain	6
4	Test Area Comparison Matrix	36

1.0 INTRODUCTION

1.1 General Introduction

Imagery of snow-covered terrains has rarely been consciously chosen for photogeological investigations when snow-free imagery was available. Snow Cover has been widely assumed to obscure rather than enhance terrestial features. This is the apparent result of the "no leaves and no snow" philosophy which is often viewed as the only criterion for successful geological applications of remote sensing data.

The principal investigator hypothesized that imagery of snow-covered terrains was a much under-utilized source of photogeological data and that the technique could facilitate the analysis of relatively low resolution data collected by ERTS and other satellite systems. With the repetitive coverate of ERTS-1, dynamic snow-cover variations could be effectively monitored and the effects of differential melting in the detection of fractures could be evaluated.

This report is an up-to-date review of the investigators analysis of ERTS imagery of snow-covered terrains. It confirms the value of snow enhancement for photogeological fracture analysis and presents the initial analytical results of ERTS snow-covered imagery. It is anticipated that this report will be an initial step in the realization of increased benefits from the usage of wintertime ERTS imagery.

1.2 Summary of Accomplishments

The principal accomplishments realized during this reporting period are briefly summarized below:

- Localized areas lacking a suitable density of snow depth reporting within EarthSat's postcard network for the New England Test Area were intensified by contacting local newspapers. An ERTS Experiment Information Package was used to further enlist volunteer support. This also served to publicize the ERTS program and availability of ERTS-1 imagery[1/]

- Readers indicating their desire to participate in the experiment were notified of data collection requirements and were sent a supply of Snow Depth Reporting Postcards.

- A snow depth recording system has been designed to display snow depth information. Base maps which illustrate the locations of all reporting observers were reproduced to allow weekly tabulation and display of snow depth information.

[1/] Further data concerning the successful use of postcard reporting can be referenced in the Bi-Monthly Progress Report for October 31-December 31, 1972.

- Excellent quality snow-free ERTS-1 transparencies (1096-15072 and 1096-15065) of the primary test area (New England) were received and the areal geology analyzed. New fracture detail within the New England Test Area was acquired as a result of this analysis.

- A lineament overlay was prepared from analysis of high altitude (1:250,000) photo index mosaics as a supplemental source in the geological validation of interpreted lineaments.

- A working fracture-annotation legend[2/] was designed to standardized lineament mapping.

- A system for lineament validation was conceptualized and is being implemented to confirm the genesis of interpreted lineaments (Table 1).

- The Data Analysis Plan was submitted to the ERTS Contracting Officer and approved.

- ERTS-1 image analysis utilizing both snow-free & snow-cover imagery confirmed that MSS bands 5 and 7 provide the greatest fracture detail for both snow-free and snow-covered terrain.

- The first ERTS-1 images (e.g. 1132-15074 and 1168-15065) of snow-covered terrain within the New England Test Area were received and analyzed (Figure 4). A comparison of detail of fracture mapping on ERTS snow-free versus snow-cover imagery appears to deomnstrate a greater quantity of fracture detail can be attained by utilizing snow-enhanced imagery (Figure 3-4).

- Field investigations were conducted within the New England Test Area coincident with the February 12 overpass of the ERTS-1 satellite. Enhancement of geological features by snow cover was confirmed. General observations are referenced in the Snow Cover Observation report.[3/]

- A snow depth isopach map has been compiled for the New England Test Area based on data supplied through EarthSat's snow depth reporting network and supplementary snow depth readings taken by the investigators.

- The isopach map is being used to compare snow depth with the fracture data yield and thus establish the working limitations of the snow enhancement technique. A preliminary assessment of the influence of snow depth on the enhancement or obscuration of geological features has been made (Table 2).

[2/] RE: Bi-Monthly Progress Report for October 31 - December 31.

[3/] RE: Bi-Monthly Progress Report for January 1 - February 28, 1973.

- Bedrock joint readings are being recorded from outcrops during field investigations and are being utilized to confirm the validity of lineaments interpreted from ERTS-1 imagery (see Figure 6).

- Low altitude, light aircraft vertical and oblique photography was collected by the investigators during the February 12 ERTS-1 overflight. A time coincident with the overpass was chosen to minimize climatic and solar illumination variables. Analysis of these data is referenced in Section 4.4.6.

- Multiband U-2 imagery of the New England Test Area has been received and is being analyzed. A summary of fracture directions interpreted from the imagery for one test site is illustrated in Figure 6. The imagery is also being utilized to validate lineaments mapped from ERTS imagery.

- A paper detailing the results, findings and projected benefits of the experiment was presented by the principal investigator at the March ERTS-1 symposium.

- Snow enhancement techniques have been made available to the mineral industry as a step leading to benefits analysis of ERTS-1 technology (Appendix E).

- Two test sites within the New England Test Area were selected to facilitate detailed photogeological analysis. An analysis of the Great Barrington, Massachusetts Test Site is included within this report. Subsequent reports will contain further analyses of the detailed test sites.

- An evaluation of individual ERTS multispectral bands for fracture detectability of snow-covered terrain was made. The results (preliminary) are contained in Table 3.

- The Final Report Outline has been revised and updated. Several sections of the Final Report have been prepared. A new section dealing with <u>benefits analysis</u> has been recommended to NASA to facilitate a prompt and practical application of snow enhancement technology.

TABLE 1: SEQUENTIAL SYSTEM FOR LINEAMENT VALIDATION[1/] -NEW ENGLAND TEST AREA
(Updated 5-15-73)

	VALIDATION	
ORDER	SOURCE	RATIONALE
1	Multiple Analysis	Lineaments mapped on overlays by one image analyst will be reinforced or eliminated by succeeding image analysts in a 3-interpreter sequential rotation of analysis.
2	Topographic Maps Reference	Topographic maps will be analyzed in sequence from small scale to large scale to check the coincidence of interpreted lineaments with cultural linear features e.g., pipelines, transmission lines, highways, ski slopes, etc. A negative correlation of interpreted lineaments with existing cultural linears would tend to indicate a geological origin.
3	Radar Lineament Map Reference	A fracture-lineament map prepared from analysis of radar mosaics will be used to further validate the geological origin of interpreted lineaments.
4	Geological Map References	Geological maps will be analyzed in sequence from small scale to large scale to check the coincidence of interpreted lineaments with mapped fractures or faults. The geological nature of the lineaments, e.g. structure, lithology, foliation, may be determined for display on annotated enlargements. Maps showing glacial striae will also be consulted.
5	Field Observation	Interpreted lineaments may be validated through direct field observation by EarthSat Scienctists.

1/ The geological validity of the image-identified lineament may be established by one or all of the final four steps in the validation order. It is likely that most lineaments will have been validitated before step five. A lineament that cannot be validated in the above system will be deleted from the overlay. The above approach may be modified at a later date.

2/ For purposes of classification this reference includes geophysical (aero-magnetic) and glacial maps as available.

TABLE 2: INFLUENCE OF SNOW DEPTH ON ENHANCEMENT OF GEOLOGICAL FEATURES

(NEW ENGLAND TEST AREA)

GEOLOGICAL FEATURE	SNOW DEPTH CATEGORIES				
	<1 inch	1-2 inches	3-6 inches	6-9 inches 2/	>9 inches 3/
Fracture - lineaments	+++	++	-	-- ?	?
Vegetation Alignments 4/	+	++	++	+++?	?
Regional Macro-Relief	0	+	++	+++?	?
Micro-Relief	+++	++	+	-?	?

1/ This table assumes (1) relatively even deposition of snow cover and (2) minimum snow ablation. Ratings change values rapidly as a function of the rate and amount of ablation.

2/ Ratings are based on a minimum of available data.

3/ Ratings cannot be applied because of a lack of deep snow cover within the New England test area.

4/ Vegetation alignments indicative of fracturing.

+++ = maximum enhancement

--- = maximum obscuration

0 = neutral effect, no enhancement or obscuration.

5

TABLE 3: EVALUATION OF FRACTURE DETECTABILITY UTILIZING MULTISPECTRAL ERTS-1 IMAGERY OF SNOW-COVERED TERRAIN

FRACTURE-LINEAMENT INDICATORS (Snow-Cover Imagery)	MSS BANDS[1/]				
	BAND 4	BAND 5	BAND 6	BAND 7	COLOR COMPOSITE
DIFFERENTIAL SNOW COVER PATTERNS	5	1	3	4	2
TOPOGRAPHIC SHADOWING	5	4	2	1	3
WATER BODY ALIGNMENT (STRAIGHT STREAM SEGMENT, LAKE BANDS, ETC.)	5	4	2	1	3
VEGETATIVE ALIGNMENTS	3	2	4	5	1

NOTE: The number one (1) indicates the band which provides the maximum information.

[1/] Band 4 (500-600nm.), Band 5 (600-700nm.), Band 6 (700-800nm.), Band 7 (800-1100nm.).

2.0 BACKGROUND

2.1 Literature Review

Analysis of Mercury, Gemini and Apollo imagery over the past five years, including that by Lowman (1967), and Wobber (1969), demonstrated useful applications of small scale photography to the resolution of geological, hydrological and environmental problems. Wobber (1972) cited the value of imagery acquired from manned spacecraft for earth resources satellite mission planning. The synoptic imaging capability of orbital imagery and its value for structural analysis are reasonably well understood and have been discussed by Lowman (1970) and Hamilton (1971).

Wobber (1969) suggested that low angle solar illumination could have value in snow-covered glacial terrain. Woloshin (1965) and Lowman (1967) used Nimbus photography with snow cover to detect the extension of a fault in the East Sayan Mountains of the USSR. Reports by Sabatini and Sissala (1968) and Sabatini et. al. (1970) included references to the fact that geological lineaments, hydrological features and outcrop patterns were enhanced by snow. The value of Nimbus imagery for detecting major structural features was recently noted by the U.S. Geological Survey (1972). Lathram reported the discovery of several previously unmapped fractures and faults in Alaska and western Canada utilizing Nimbus imagery of heavily snow-covered terrain.

Using Gemini photographs, Wobber (unpublished research, 1970-1971) determined that snow cover proved useful for enhancing fracture lineaments, and accentuated lithological differences. Lowman (personal communication, 1972) also observed that the presence of snow cover enhanced structural features. Nicks (1970) noted from interpretations of Apollo photographs that snow sometimes enhanced fracture patterns.

Recently, W.D. Carter (personal communication, 1972) of the U.S. Geological Survey observed a circular feature on Apollo-9 photographs of snow-covered terrain in Southeastern Arizona. Following geological and geophysical studies, Bromfield, et. al., (1972) judged that the circular feature was a visual result of a favorable sun angle and shadowing caused by an intersecting fault pattern.

2.2 Pre-ERTS Investigations

Aerial photography of non-polar areas containing significant snow cover is generally difficult to obtain. Photographs of snow-covered terrain in temperate areas obtained during winter military exercises are usually classified, and unavailable for geological study. Between 1965 and 1970, the senior author collected oblique color photography of recently snow-covered areas in the mid-western United States. Linear features including bedding planes, and probable joints and faults appeared to be enhanced. The utility of oblique imaging, as a tool for fracture detection in snow-covered terrain was confirmed. These isolated photographs were collected under conditions of relatively high angle solar illumination, and variations in snow depth were not measured. The working limitations of the technique, therefore were difficult to establish. Lacking repetitive coverage, enhancement of structural details by differential snow melting patterns could not be tested.

Available ERTS-analog (Mercury, Gemini, Apollo, Nimbus) and ERTS-simulation imagery of snow-covered terrain was selectively analyzed by the investigators in preparation for ERTS-1. Particular attention was focused on the interpretation of ERTS-simulation imagery of snow-covered terrain in the Feather River/Lake Tahoe area. Four sequential flights1/ of this multiband imagery were analyzed to assess the value of snow enhancement as a photogeological technique.

In addition to manual analysis of snow-covered imagery, several viewing techniques were utilized for speeding the analysis of snow-covered imagery. These techniques add a further level of enhancement to the natural enhancement provided by a combination of snow cover and low angle solar illumination. One of the techniques which appeared particularly suited to fracture analysis was the film sandwich.

The film sandwich, or film stack involves the superposition of a black-and-white negative transparency upon its positive counterpart. Offsetting or shifting the transparencies tends to accentuate linear features, and increases the ease with which they can be discriminated. Textures are subdued while macro-patterns (produced by textures and contrast) are lost. Bright lines are created along the contacts of high contrast areas which accentuate features of moderate to low, positive or negative relief.

Delwig et. al. (1970) also discussed a film sandwich method which he employed solely for the purpose of obtaining a "pseudo" three dimensional effect with monoscopic radar imagery. Weller (1970) applied the technique to the interpretation of lunar features.

2.3 Concept of Snow Enhancement

Geological structure and lithology exert a strong influence on surface relief. Fractures (joints and faults) are usually more easily eroded than surrounding rock, producing linear to curvilinear surface depressions which are frequently imaged with dark-tones. Utilizing imagery with snow cover, fractures stand out in contrast to surrounding terrain because of (a) an absence of snow cover, (b) accentuation of variations in vegetative cover, and/or (c) shadowing. The apparent absence of snow cover is attributed to accelerated melting rates induced by the higher moisture content of subsurface materials in fracture zones or, the obscuration of snow cover by vegetative overstory. Low angle solar illumination provides a pseudo-radar effect and produces shadows which emphasize subtle relief differences.

1/ Imagery was acquired on the following dates: 8 December 1971, 20 December 1971, 31 January 1972 and 6 March 1972.

Gray scale variances introduce unnecessary background detail reducing the effectiveness of the photogeologist during his interpretive process. Snow-covered terrain tends to reduce background "noise", thereby simplifying the interpretation process. For example, grass-covered areas present a uniform and homogeneous appearance when the ground is thickly snow-covered. The accompanying reduction in overall gray scale variance with snow cover reduces the threshold of lineament detection, and increases the total number of identifiable lineaments. Additionally, increased tonal contrasts along a given snow-covered/snow-free interface provide a form of natural edge enhancement for low resolution imagery.

New snowfall patterns or differential snow melting patterns within unfrozen materials are diagnostic of variations in the moisture content (and hence thermal properties) of surface and subsurface materials. This is significant in that fracture zones commonly have a higher moisture content than surrounding areas.

The investigators are evaluating the contribution of low sun angle as a complement to snow enhancement to increase fracture detectability. Image analysts have long recognized that topographic changes can be detected when sun-facing slopes are illuminated and back slopes are in darkness. This situation is analogous to side-looking airborne radar (SLAR) imagery flown parallel or near parallel to structural trends. Slopes facing the aircraft give strong (bright) returns while far slopes produce a black radar shadow.

Low angle solar illumination contributes to discrimination of topographically-expressed structural lineaments, however, it is unlikely that low angle solar illumination alone will permit subtle linear or textural features (including faults in glaciated terrain) to be detected from low resolution imagery without additional enhancement. Differential snow melt patterns (related to bedrock fracturing) when combined with low angle solar illumination, aid in the detection of subtle fractures with subdued surface expression by increasing the tonal contrast of the topographically shadowed lineament against the highly illuminated snow-covered background. It is on this premise that snow enhancement as an interpretive technique for photogeological studies is based.

3.0 ANALYTICAL PROCEDURES AND TECHNIQUES

3.1 Analysis Procedures

As of this reporting date, all in-house imagery has been analyzed. Fracture annotated overlays have been routinely derived for each medium-high quality image of the New England Test Area. Individual test sites have been selected within this test area for intensive analysis. A variety of enhancement techniques will be tested within these sites to ensure completeness in describing analytical procedures in the NDPF User Manual.

Within the Maryland-Virginia Test Area a complete lack of measurable snowfall was reported. Supplementary data (e.g. geological maps, topographic maps, geological articles and reports, etc.) were assembled and initial fall field studies conducted. Additionally, a snow depth postcard reporting network was established within this area. This data however, cannot be put to a productive use in the absence of snow-covered data. The investigators are recommending a funded extension of the experiment to facilitate the acquisition of snow-covered images for this test area (See Section 9.0 RECOMMENDATIONS).

3.2 Analysis Techniques

In addition to the "natural" form of enhancement which snow-cover and low angle solar illumination provide, several viewing techniques are being utilized to supplement fracture analysis of snow-free and snow-covered areas. The techniques include additive color presentations, density slicing, film sandwiching and use of a Ronchi grating. Controlled tests of all these techniques will be conducted during the next reporting period. Preliminary findings on the utility of additive color, density slicing and film sandwiching techniques are discussed in the following sub-sections.

3.2.1 Additive Color Presentations

ERTS-1 images of snow-covered and snow-free terrain were studied utilizing additive combination of MSS bands 4,5 and 7. Positive and negative transparencies were utilized. A wide variety of filter combinations were tested. Preliminary findings include:

- Additive color presentation furnished new fracture information (e.g., accentuation of vegetative alignments related to fracture control).

- Negative transparencies in some cases enhanced snow-covered (light-toned) lineations (e.g. transmission lines) which were generally of cultural origin.

- Vegetative alignments were more conspicuously rendered utilizing standard filter-band assignments (i.e., MSS bands 4, 5 and 7 combined with blue, green and red filters respectively) and positive transparencies.

3.2.2 Density Slicing

Density slicing equipment (Digicol) was tested for discriminating varying depths of snow cover. A color panel containing 32 colors was applied to an ERTS-1 positive transparency. The image (1132-15074) was acquired on December 2, 1972 over snow-covered terrain within the New England Test Area. Various color combinations and gain settings were used. Density slicing discriminations were compared with a snow depth isopach map compiled from data supplied by EarthSats Snow Depth Reporting System. Preliminary findings include:

- A minimum of three ground cover categories were reliably attainable utilizing density slicing-snow-free, <1 inch, and >1 inch. It was hypothesized that another category (1-4 inches) could be attained under certain conditions i.e., where terrain was predominantly covered with low growth vegetation (e.g. grassland or meadow) and land use was not mixed.

- Snow depth information could not be reliably extrapolated form open areas into or through large areas of confierous tree cover.

3.2.3 Film Sandwich

Film sandwich tests were conducted utilizing snow-free ERTS-1 images (1096-15065 and 1096-15072) collected on October 27, 1972. Positive and negatives transparencies were overlaid and shifted to produce a slight offset. Enhancement of major boundaries (e.g. land/water interface) was noted; subtle boundaries could not be distinguished due to the extremely high density of the negatives for these images. Tests will be conducted during the next reporting period utilizing medium density transparencies of snow-covered terrain.

3.3 Field Investigations

Extensive field observations were made within the New England Test Area during the period of the February 12 ERTS overpass. Approximately 75 snow depth readings were taken throughout central and western Massachusetts and northern Connecticut. These readings have been combined with postcard observations to compile detailed snow depth isopach maps which are being utilized to determine the influence of snow depth on data yield. (See Table 2).

A light aircraft flight was made between 8:30am - 10:45pm on February 12th to coincide with the ERTS overflight. Cruising altitude was between 4,000 - 5,000 feet. Handheld color and black and white photography of the New England Test Area was acquired. Several high density fracture zones were identified within the test areas from light aircraft. Actual enhancement of fractures and bedding surfaces by snow-cover was observed. Fractures were generally slightly darker-toned than surrounding snow-covered areas. Both differential melting and topographic shadowing were believed to contribute to the darker tone. Subtle topographic differences reflecting fractures were accentuated by slight shadowing due to the relatively low sun angle.

Vegetative differences contributed to the observed tonal differences between fractures and surrounding terrain. Coniferous vegetation was observed to be located in some fracture zones. Fracturing was comparatively difficult to detect in areas of dense coniferous tree cover.

Approximately 50 strike and dip measurements of joints were made on bedrock outcrops throughout western Massachusetts and Connecticut. These measurements have been used to validate fractures mapped from orbital and aircraft imagery. Preliminary analysis of multisensor imagery indicates that fracture detail interpreted to date (See Section 4.4) correlates well with field measurements of bedrock jointing (Figure 6).

3.4 Fracture-Lineament Validation

The investigators have developed a fracture-lineament validation system (Table 1) which is designed to differentiate natural geological lineaments from cultural linear features in areas of sporadically exposed bedrock such as the New England test area*. The system utilizes the inputs of trained interpretors, topographic maps, geological maps, radar lineament maps (prepared independently by EarthSat) and bedrock joint readings obtained in the field. The system is designed to add (or subtract) succesive "weight" to a mapped lineament by checking its coincidence with existing data.

* The validation system may not apply or may require modification for the Maryland-Virginia test area.

Fracture-lineaments which meet validation criteria will be recorded on the ERTS photo base map for western Massachusetts (See Section 7.0 PROGRAM FOR NEXT REPORTING PERIOD).

3.5 Selection of Detailed Test Sites

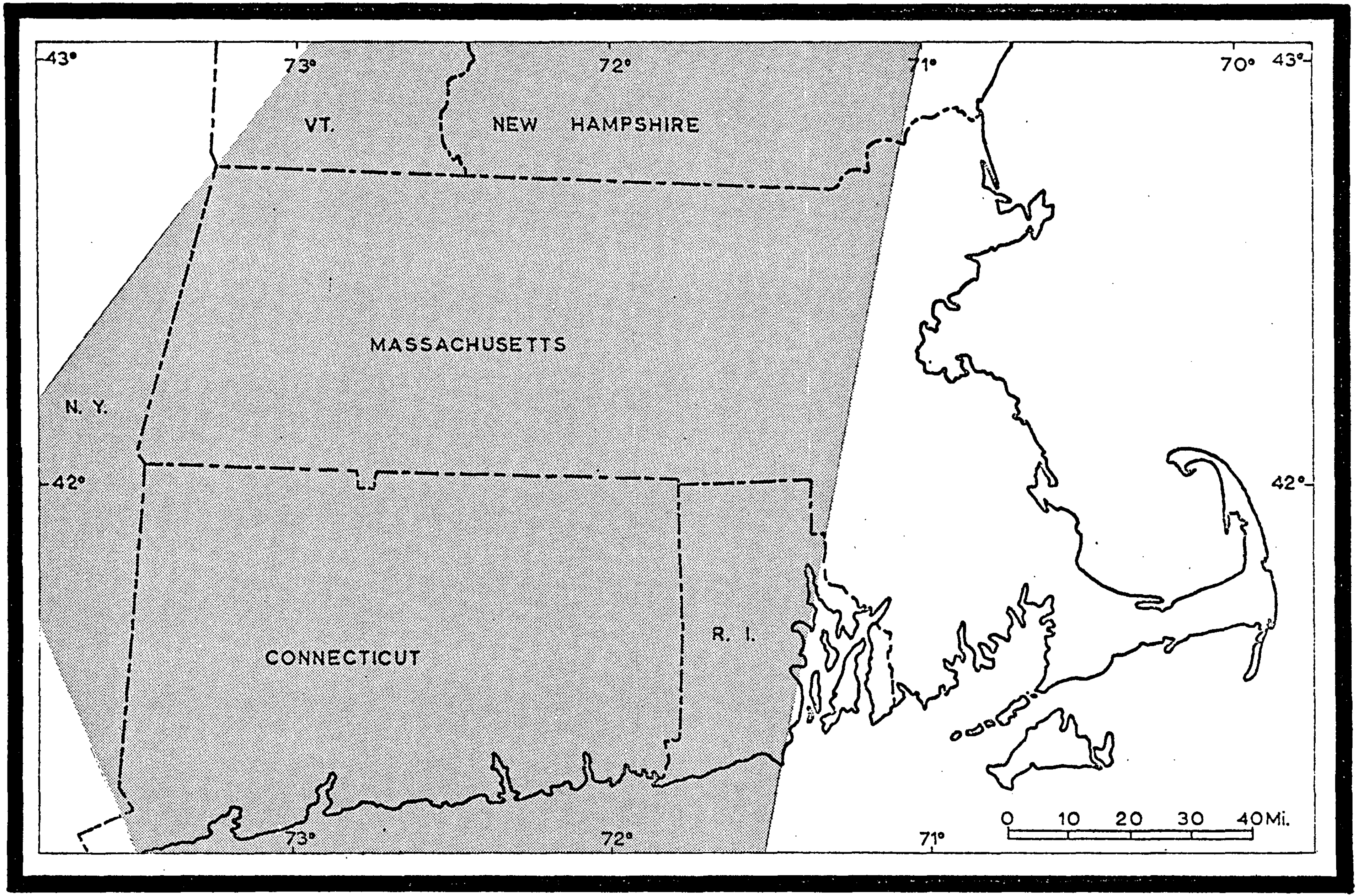
An intensive review of the New England Test Area has resulted in the selection of two primary test sites1/ for detailed geological analysis. The sites were chosen from areas with abundant snow cover, complex geological structure and subtle (not well-defined) bedrock jointing. Additionally, the limitations of existing geological data were evaluated in an effort to select areas where new geological data could be contributed.

For each test site, a detailed geological analysis is being conducted utilizing a variety of available remote sensing records including snow-covered ERTS, snow-free ERTS, high altitude aircraft CIR, SLAR and aeromagnetic data. These data are analyzed and the results correlated with field geological measurements. Techniques refined from these analyses will serve as guidelines in fracture mapping for the remainder of the test area and will be documented in the NDPF Users Manual.

An initial photogeological analysis of the Great Barrington, Massachusetts Test Site (Test Site #1) has already been conducted. The results are discussed in the following section.

1/ Secondary test sites may be selected at a later date as needed.

FIGURE 1: New England Test Area



71

4.0 MULTI-SENSOR DATA ANALYSIS OF TEST SITE #1 (Great Barrington, Massachusetts

4.1 Geographic Location and Site Selection Rationale

The Great Barrington area is located in western Massachusetts and bounded by coordinates 73°05 - 73°20' and 42°-10' - 42°25'. The area includes a portion of the western edge of the Berkshire Mountains on the east and segments of the Taconic Mountains on the west. The Great Barrington area was chosen as a test site for the following reasons:

- It is a geologically complex area of varied rock types and structures, which allows evaluation of snow enhancement capabilities in diverse terrain and bedrock types.

- It is located within the western Massachusetts snow belt where opportunities to observe transient snow melt phenomena are maximized.

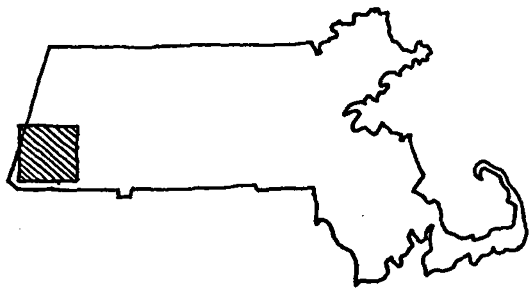
- Geologic mapping has not been extensively conducted within this area providing a chance to contribute useful data.

4.2 General Geology

The Great Barrington Test Site lies along the western front of the Berkshire Massif, a Precambrian core of igneous and metamorphic rocks which have been thrust westward over Cambrian and Ordovician metasedimentary rocks (Figure 2). The western edge of the Berkshires is defined by a thrust-fault. The feature creates a prominent regional topographic break since the rocks of the massif are considerably more resistant to weathering than the adjacent marble of the Stockbridge - Great Barrington Valley. Several smaller ridges are isolated thrust-faulted remnants of more resistant rock including the Cheshire Quartzite and Everett Schist.

At least three major episodes of tectonic activity have altered the rocks of this area. The earliest episode (Grenville orogeny) involved the intrusion of igneous rock, high-grade metamorphisim, and development of folds and faults in a north-

Figure 2. : Geologic Map of the Great Barrington, Massachusetts area. From Albany 1:250,000 scale Geological Sheet, New York Geological Survey. Location of area shown on map to the right.



EXPLANATION

Owl	Waloomsac schist	Ordovician
OCst	Stockbridge marble	
Ccd	Cheshire quartzite	Cambrian
€ev	Everett schist	
mu	Undivided metasediments	
am	Amphibolite	Precambrian
bg	Biotite granitic gneiss	

Thrust fault - teeth, overthrust block

High-angle fault

Lithologic contact

westerly trend. Subsequent to deposition of the Middle Ordovician Walloomsac Schist, the Precambrian and lower Paleozoic rocks were deformed (Taconic orogeny) into a series of tight folds.

Major thrusting moved both the Taconic Mountains and the Berkshire Massif to their present positions. The latest episode (Acadian orogeny) involved high-grade regional metamorphism and granitic intrusion.

4.3 Field Observation

The strike of folds in the Berkshire Massif was determined through field measurements obtained from joint systems in the Walloomsac Schist, Stockbridge Marble, Cheshire Quartzite and Precambrian Granitic-Gneiss. These measurements indicate several major joint systems - N 20°-30°W, N70°-90°W, and N20°-30°E (Figure 6). From field investigations, bedrock lithologies were recorded for key areas; the extent of glacial till cover was also noted. Snow depth readings were made throughout the area. The variations in snow cover were observed to be related to differences in cover types and topographic forms. 1/

4.4 Analysis of Multi-Sensor Data for the Great Barrington Test Site

The Great Barrington Test Site was studied utilizing five different sources of remote sensor data including: Side-Looking Airborne Radar (SLAR) imagery (1:500,000), Aero-Magnetic Data, U-2 Color Infrared Photography (CIR) (1:120,000), ERTS snow-free imagery (October 27, 1972), and ERTS snow-covered imagery (December 2, 1972). Supplementary color photography was acquired from a light aircraft at 4,000 feet during the February 12 field investigation and used to validate fractures mapped from smaller scale imagery. Analysis was confined to manual interpretation of transparencies and prints. Lineaments (including fractures and structural boundaries) were mapped from interpretation of each data source. A study of the correlation between geological features intepreted from each sensor and available ground truth data (including field data collected by EarthSat and existing geologic maps) was made. An interpretation of the test site and an evaluation of the utility of each sensor for photogeological analysis follows.

1/ Reference Bi-Monthly Progress Report of December 31, 1972 - February 28, 1973 for a complete report of this investigation.

4.4.1 ERTS Imagery (Snow Free)

An intensive analysis was conducted of snow-free ERTS-1 image (1096-15072-7) of the Great Barrington Test Site. Lineaments (including fractures and structural boundaries) were interpreted from the ERTS-1 image (Figure 3). Sun elevation for this image was approximately 31 degrees (above the horizon) at the time of overflight.

4.4.2 ERTS Imagery (Snow-Covered)

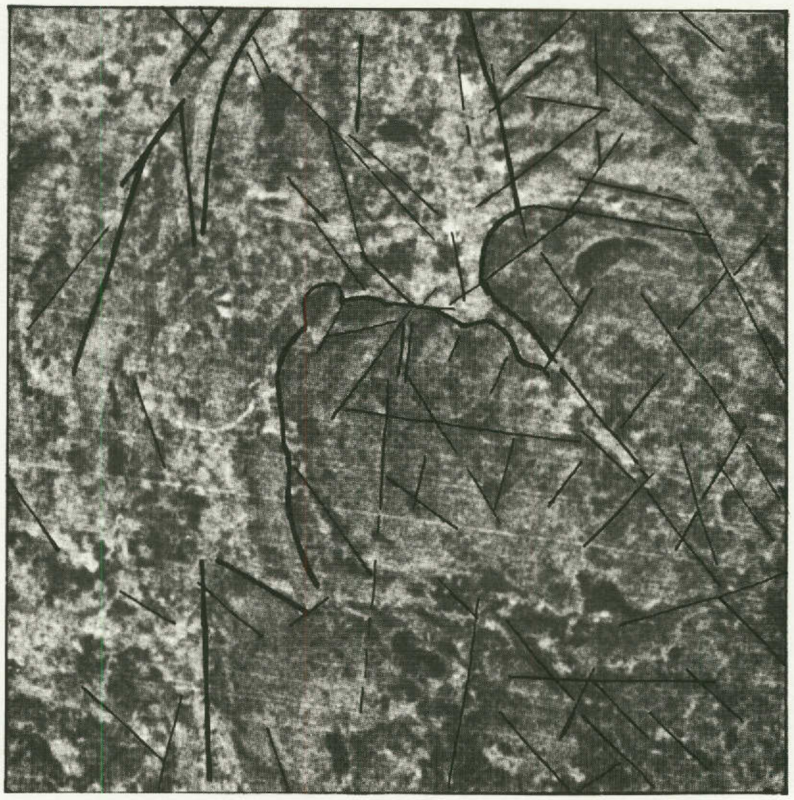
An ERTS-1 snow-covered image (1132-15074-7) collected on December 2, 1972 was analyzed for the same length of time as the snow-free image (Figure 4).1/ Interpreted linear data were plotted on a fracture rose diagram for comparison with ground truth data obtained from the analysis of other imagery (Figure 6). The thrust-faulted boundary of the Berkshire Massif is readily apparent on the imagery. A heavy snow cover on the Berkshire Mountains contrasts readily with the thin to bare cover on the adjacent valley. The snow cover within the test site varied from 1-8 inches at the time of image acquisition. The deeper snow cover was considered to provide maximum enhancement for macro-relief features and for vegetative alignments indicative of fracture control (See Table 2). Numerous fractures which coincide with those mapped on the snow-covered CIR photography and SLAR imagery are also evident. A low sun angle (22 degrees) appeared to accentuate topographic relief related to bedrock structure.

4.4.3 Side-Looking Airborne Radar (SLAR) Imagery

SLAR imagery (Figure 5) acquired at a scale of 1:500,000 was analyzed utilizing the east-looking direction. Fractures, faults, lineaments, bedding and/or foliation trends were mapped. Interpretation of the SLAR imagery shows the thrust fault boundary of the Berkshire Massif, thrust fault slices and remnants of Taconic rocks to the west, and several smaller high-angle faults. Numerous fractures were interpreted from the imagery; a summary of fracture plots indicates a major direction

1/ Considerable time elapsed between the interpretation of the October 27 (snow-free) image and the December 2 (snow-cover) image so as to reduce the importance of the learning factor in image analysis of the same area.

A.



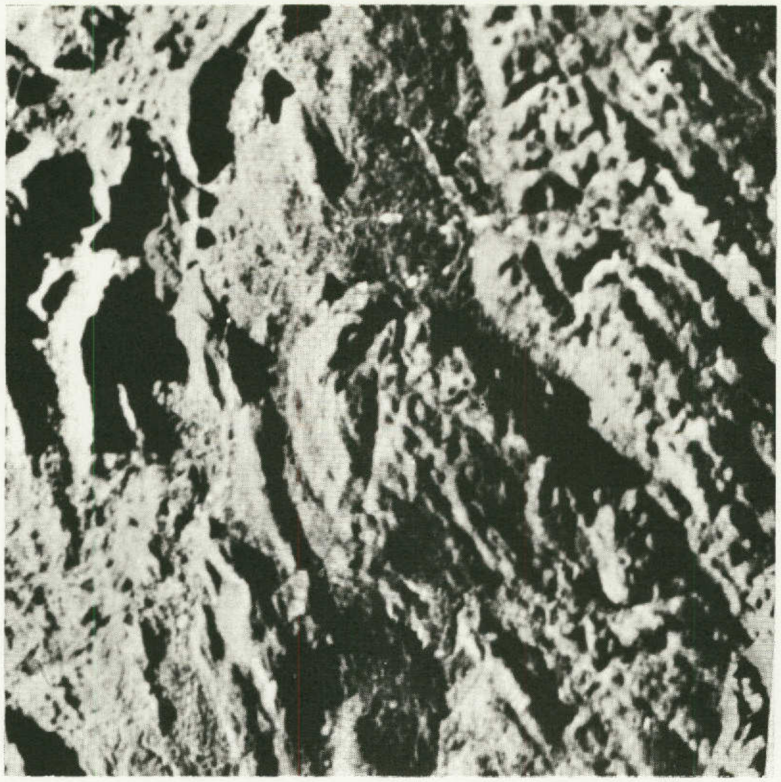
B.

Figure 3: ERTS-1 snow-free image (1096-15072-7) collected on December 2, 1972 (A) and fracture annotated image (B) of the Great Barrington, Massachusetts test site illustrating fractures (——) and major structural boundaries (━━) interpreted from the imagery (1:250,000 scale).

A.

B.

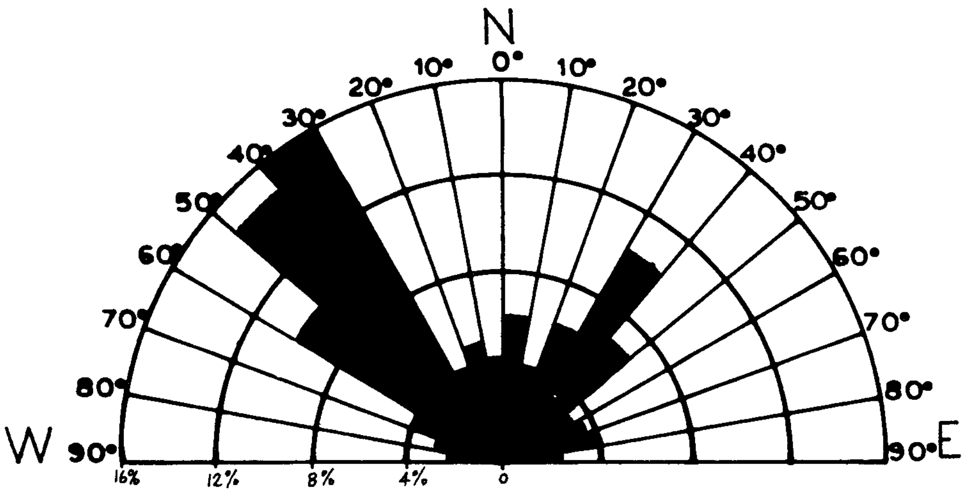
Figure 4: ERTS-1 snow-covered image (1132-15074) collected on February 13, 1973 (A) and fracture annotated image (B) of the Great Barrington, Massachusetts test site illustrating fractures (——) and major structural boundaries (▬▬) interpreted from the imagery (1:250,000 scale).



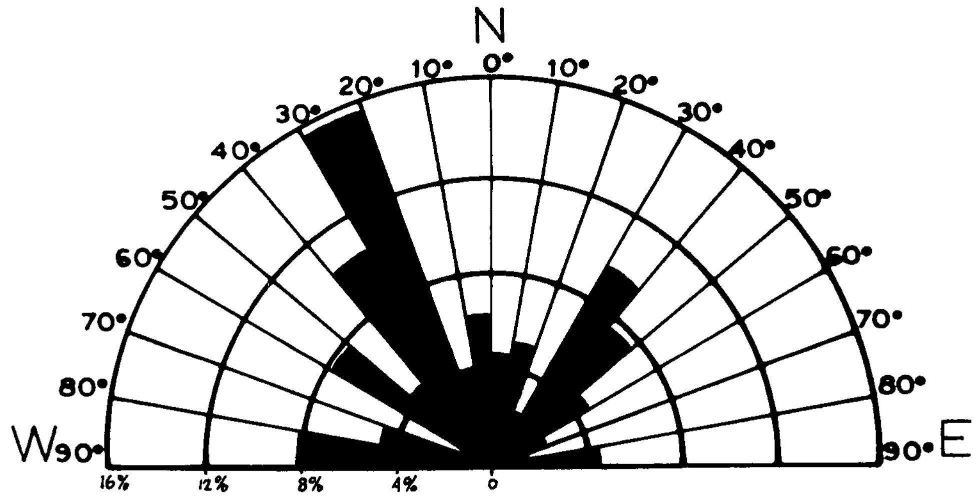
A.

B.

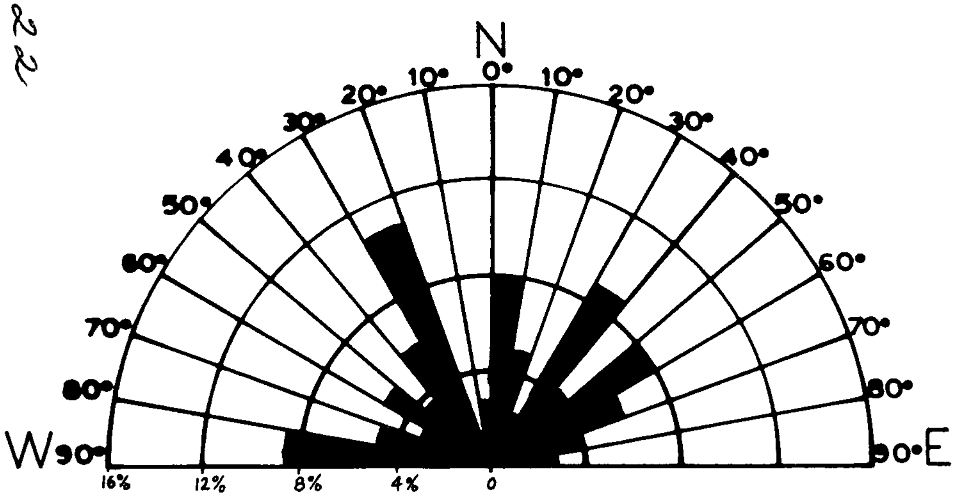
Figure 5: SLAR (east-looking) image (A) and fracture annotated image (B) of the Great Barrington, Massachusetts test site illustrating fractures (——) and major structural boundaries (——) interpreted from the imagery (1:250,000 scale).



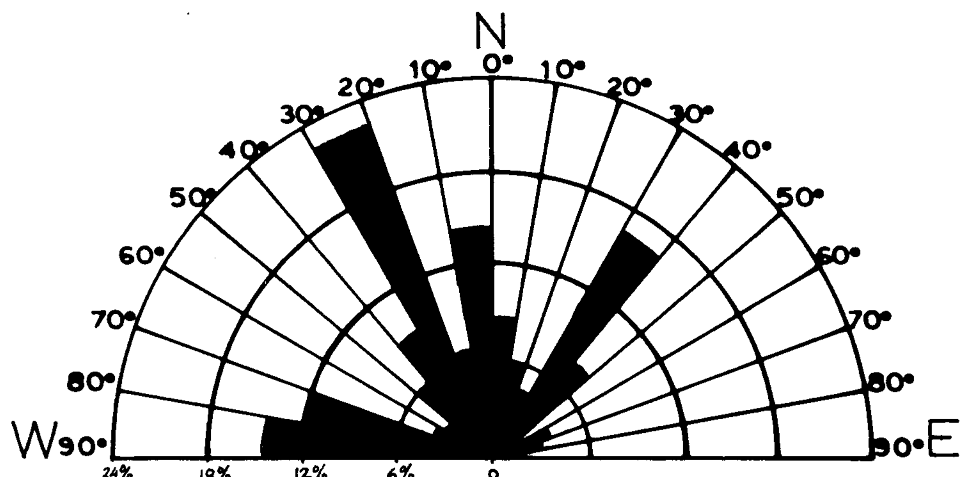
A. Measurement summary of fractures interpreted from SLAR imagery.



B. Measurement summary of fractures interpreted from color infrared (U-2) imagery (snow covered).



C. Measurement summary of fractures interpreted from ERTS-1 snow-covered imagery.



D. Measurement summary of bedrock joints obtained from field investigations.

FIGURE 6. Rose diagram directional summaries of geologic fractures interpreted from multi-sensor imagery of the Great Barrington, Massachusetts test site.

between N30° and N40°W and a minor direction of N40°-50°W which does not correlate well with field measurements. (Figure 6). This discrepancy may be related to distortions within the original SLAR imaging system or to distortions introduced in the radar mosaicking process. These directions correlate well with field joint measurements and reasonably substantiate the accuracy of SLAR fracture analysis.

4.4.4 USGS Aeromagnetic Maps

Aeromagnetic data compiled by the USGS at a scale of 1:250,000 was obtained for the entire New England Test Area. An analysis of the Great Barrington Test Site was conducted utilizing this data (Figure 7). A study of the correlation between the magnetic anomalies and major structural trends interpreted from ERTS, SLAR, and CIR imagery was made. Fractures interpreted from the snow-covered ERTS imagery correlate well with strong lineaments on the aeromagnetic maps, however, the shorter linear elements are not readily apparent from the aeromagnetic data. It appears that the use of ERTS imagery (especially imagery of snow-covered terrains) in combination with aeromagnetic data could provide an important tool for regional mineral exploration. This may be particularly true in northern latitudes where sporadic snow cover exists throughout much of the year and bare ground or bedrock may be infrequently exposed.

4.4.5 High Altitude Color Infrared Photography (Snow Covered)

Snow-covered color infrared photography of the Great Barrington Test Site was acquired on January 31, 1973 by U-2 aircraft at an altitude of 60,000 feet - resulting photo scale 1:120,000. The photography served as a source of validation for geological features mapped on the ERTS imagery. A number of more subtle and generally shorter fractures were interpreted from the CIR photography which were not evident on the SLAR or ERTS imagery. This was attributed primarily to the greater resolution of the CIR photography which facilitated the detection of more subtle fracture systems beyond the normal resolution of the other sensors. A summary plot of the directions of fractures

Figure 7. U.S.G.S. Aeromagnetic map at 1:250,000 scale of the Great Barrington test site (outlined) and surrounding areas in western Massachusetts. The arrows point to linear magnetic anomalies which correlate closely with fracture zones and major structural trends seen on ERTS-1 and SLAR imagery of the area.

mapped on the CIR correlated to a higher degree with the ground truth data than any of the other sensors which were utilized. Dominant strike directions were; N20°-40°W, N80°-90°W, and N30°-50°E.

4.4.6 Low Altitude (Light Aircraft) Oblique Color Photography

A light aircraft (Cessna 160) overflight of the New England Test Area was made on the morning of February 12, 1973. The area was predominately snow-covered at the time of overflight. At an altitude of 4,000 feet, 35mm color slides were acquired and visual observations were recorded. Numerous fractures were observed and photographed; included were several areas of intense fracture development. Fractures detected from analysis of ERTS and SLAR imagery were observed and validated as were subtle fracture systems which were previously undetected. Actual enhancement of geological features (such as faults, fractures, bedrock dip, cleavage, and foliation) by snow cover was observed.

4.5 Results and Conclusions

A comparison of the linear geological features (e.g., faults, fractures and lineaments) interpreted from multi-sensor data indicates a high degree of correlation between the interpretations. Comparison with other imagery showed that a majority of fractures and structural trends were not as evident on the ERTS snow-free image. This was attributed to the lack of a contrasting medium (e.g., snow) which would accentuate structural features. This finding emphasizes the need for multi-seasonal, repetitive coverage in order to obtain the maximum yield of geological information from ERTS imagery. Additionally, the lower sun angle of the snow-cover image (22 degrees) accentuated to a greater extent topographic relief related to bedrock structure.

The snow-covered ERTS image yielded considerably more geologic information than the snow-free image and only slightly less than the aircraft (SLAR and U-2 CIR) imagery. The greater number of fractures interpreted from the CIR photography was attributed to the greater resolution (and larger scale) of the CIR which facilitated the detection of subtle fractures beyond the resolution of the other sensors.

An excellent correlation exists between the major fracture-lineament directions and the strike of bedrock joints mapped in the field. This indicates that many of the linear features interpreted from the various types of imagery are surficial expressions of the structural configuration of the bedrock.

The difference in the numbers, spacing, and orientation of fractures mapped on the various types of bedrock is also significant. Fractures in the crystalline Precambrian rocks of the Berkshire Massif are prevalent in at least four dominant directions and are much more numerous, and more closely spaced than the fractures within the Cambrian and Ordovician metasedimentary rocks west of the Berkshire thrust. The metasedimentary rocks are less intensively fractured and have only two dominant fracture directions suggesting that the crystalline rocks underwent at least one more period of tensile stress. This deduction emphasizes the potential use of systematic fracture analysis (especially using snow-covered imagery) for determining multiple periods of tectonic activity, even in areas lacking widespread bedrock exposure or having long-term snow cover.

The utilization of aeromagnetic intensity maps adds a new dimension to the photogeological analysis of satellite data, especially in snow-covered areas where bedrock outcrops are frequently not visible on the imagery. This may be of considerable value in regionally-based mineral exploration particularly in snow-covered terrains.

5.0 SIGNIFICANT RESULTS

5.1 General Results and Findings

As of this reporting date all in-house imagery has been analyzed. Fracture annotated overlays have been routinely derived for each medium-high quality ERTS-1 image of snow-free and snow-covered terrain. MSS bands 5 and 7 were found most useful for fracture analysis.

New fracture detail, which did not appear on available geological maps of the New England Test Area, was extracted through ERTS image analysis. In particular, snow cover provides increased tonal contrast of ground features and is especially useful in the detection of bedrock fractures. For a given area the same fracture systems were not as readily detectable in the fall due to the lack of a contrasting ground surface medium and the higher sun angle.

A variety of viewing techniques (e.g., additive color presentations, density slicing, film sandwiching, Ronchi grating, etc.) are being tested for fracture analysis. Additive color was found to contribute to the detection of vegetative alignments related to fracture control. Preliminary tests of density slicing indicated its ability to distinguish at least three ground/snow cover categories. Medium density transparencies were found necessary to effectively apply film sandwiching for edge enhancement.

A multi-sensor analysis of the Great Barrington, Massachusetts Test Site was conducted. Lineaments (including fractures and structural boundaries) were interpreted from ERTS snow-free imagery, ERTS snow-covered imagery, SLAR imagery, CIR photography and aeromagnetic maps.

A comparison of the linear geologic features interpreted from the multi-sensor data sources indicated a high degree of correlation between the interpreted lineaments. The snow-covered ERTS image yielded considerably more geologic information than the snow-free image of the same test site, although it yielded slightly less than from the aircraft (U-2 CIR and SLAR) imagery.

An excellent correlation was found to exist between the major fracture-lineament directions and the strike of bedrock joints recorded in the field. This indicated that the fracture-lineaments were surficial expressions of the structural configuration of the bedrock.

A difference in the numbers, spacing and orientation of fractures was found to be related to the degree of tectonic activity of various types of bedrock occurring within the test site. This suggested the potential for utilizing systematic fracture analysis including number, spacing and orientation of fractures to determine multiple periods of tectonic activity even in areas lacking widespread bedrock exposure or having long-term snow cover.

A citizen supported ground data reporting network, as utilized in this experiment, appears to be an effective means for periodically acquiring ground data. The use of postcards provides a method which is inexpensive compared with the cost of a similarly scaled direct field effort.

The utilization of aeromagnetic intensity maps adds a new dimension to the photogeological analysis of satellite data, especially in snow-covered areas where bedrock outcrops are frequently not visible on the imagery.

5.2 Summary of Significant Results

5.2.1 Results/Findings

- New fracture detail within the New England Test Area has been acquired using ERTS-1 imagery.
- Fracture-lineaments interpreted from multi-sensor imagery correlated well with the directions of bedrock joints mapped in the field indicating the validity of the mapped lineaments.
- Snow-cover in combination with low angle solar illumination has provided added enhancement for viewing and detecting topographically expressed fractures and faults.
- Additive color presentations were found useful for accentuating vegetative alignments related to fracture control.
- Heavy snow-cover (e.g. $>$ 9 inches) accentuates geological features of major topographic expression.
- Light snow dusting (e.g. $<$1 inch) accentuates subtle fracture detail.
- Vegetative alignments indicative of fracture control were frequently observed to be enhanced by snow-cover[1/].
- Use of aeromagnetic data enhances the analysis of satellite data especially in snow-covered areas of infrequent bedrock exposure.

5.2.2 Projected Benefits

- Greater fracture detail (than can be detected during the fall) may be extracted in some areas during the winter because of the higher surface contrast which snow provides and the shadowing effect of low angle solar illumination.
- Development of snow enhancement techniques promotes the full utilization of the large volume of available wintertime ERTS imagery.
- Photogeological fracture mapping will be accelerated under some conditions by proper utilization of snow cover as an enhancement tool.

[1/] Established from light altitude aircraft coverage.

- Establishment of an effective mail-based method for obtaining ground truth (snow depth) information over an extensive area. The method is both efficient and inexpensive compared with the cost of a similarly scaled direct field checking effort.
- Evolution and development of the experiment within a short period of time from a research oriented project toward a practical, cost effective method of obtaining geological data.
- Technique has been made available to mining industry.
- Application of snow-enhancement techniques to fracture mapping for excavation and civil engineering studies is strongly suggested.

6.0 NEW TECHNOLOGY

As of this reporting date, no new technological processes have been developed.

7.0 PROGRAM FOR NEXT REPORTING PERIOD

7.1 Procedural Analysis

Fractures interpreted from analysis of 70mm transparencies and 9 inch prints have been routinely recorded on 9" X 9" clear acetate overlays. During the next reporting period an ERTS photo base map will be prepared to consolidate and display all fracture - lineament detail. The ERTS photo base map will show the area of western Massachusetts at a scale of 1:250,000. It is anticipated that several overlays will be prepared to display (for example); (1) fractures interpreted from snow-free ERTS-1 imagery as compared with; (2) fractures interpreted from imagery of snow-covered terrains. The overlays will document the detectability of fractures utilizing ERTS imagery.

A comparative test of fracture mapping utilizing imagery of snow-free and snow-covered terrain is also planned for the next period. The test will be performed by two senior photogeologists who have not previously participated in this investigation. The test will be carefully controlled utilizing similar quality imagery of the New England Test Area acquired on two separate dates - October 27, 1972 and February 12, 1973. The October image is completely snow-free; the February image contains snow-cover in varying amounts. Results of this test should aid in the conclusive determination of the enhancemente value of snow-cover for photogeological fracture mapping.

A summary of additional projects to be undertaken during the next reporting period is included in the following section.

7.2 Task Summary

A capsulized summary of the tasks to be conducted within the next reporting period follows:

- Continue analysis of all in-coming ERTS imagery.
- Conduct intensive analysis of Test Site #2 utilizing multi-sensor data.
- Generate automated (enhanced) fracture rosette of computer enhanced imagery and/or computer enhanced images of snow-free and snow-covered terrain within Test Site #1.

- Validate and consolidate onto a base overlay all lineaments mapped from snow-free and snow-covered ERTS imagery

- Continue preparation of Final Report sections

- Conduct controlled test of relative effectiveness of viewing techniques (e.g. additive color, film sandwich, and Ronchi grating) for fracture enhancement (See Section 3.2 for preliminary assessments).

- Begin preparation of NDPF Snow-Enhancement Users Manual

7.3 Anticipated Principal Products

Principal products generated from this period are anticipated to include:

- ERTS photobase maps (1:250,000 scale) illustrating comparative fracture detail extracted from analysis of snow-free and snow-cover ERTS data.

- Automated fracture rosette of computer enhanced imagery and/or computer enhanced images of snow-free and snow-covered terrain.

- Multi-sensor analysis of Test Site #2 complete with illustrations and concise summary text documenting the value of snow-enhancement.

- Validation and consolidation (onto a standard format) of all fracture detail interpreted from ERTS-1 imagery (both snow-free and snow-cover) within the New England Test Area.

- Detectability matrices of fracture lineaments and environmental geological features for each multispectral band

- Snow enhancement techniques matrix defining the enhancement capabilities of snow cover (e.g., snow dusting, differential snow melt patterns, vegetal snow obscuration, etc.).

8.0 CONCLUSIONS

Analysis of ERTS-1 imagery provides an effective means of acquiring structural geological data. Snow-cover in combination with low-angle solar illumination provides increased tonal contrast of surface features and is especially useful in the detection of bedrock fractures. Within the test area the same fracture systems were not as readily detectable in the fall due to the lack of a contrasting ground surface medium and a relatively high sun-angle. The MSS bands most useful for the detection of fractures in both snow-free and snow-covered terrain were judged to be bands 5 and 7.

Low angle solar illumination has been observed to emphasize topographic expressions which are not as apparent on imagery acquired with a high sun angle. A difference of nine degrees (between 31 and 22 degrees) significantly augmented topographic shadowing. Viewing techniques (e.g. additive color, density slicing, film sandwiching, Ronchi grating) currently being tested promise to supply additional enhancement to the natural enhancement provided by snow cover and low angle solar illumination.

The utilization of a citizen supported ground data reporting network appears to be practical and effective means for periodically acquiring ground data. Significant citizen interest in on-going NASA programs was found to exist. The use of postcards provides a method which is inexpensive compared with the cost of a similarly scaled direct field effort.

Extension of snow enhancement techniques from temperate areas to areas of permanent snow cover for acquisition of geological data appears likely. This seems particularly true since relatively deep snow (e.g. >9 inches) was found to enhance certain topographic features indicative of geologic structure.

The utilization of aeromagnetic intensity maps adds a new dimension to the photogeological analysis of satellite data, especially in snow-covered areas where bedrock outcrops are frequently not visible on the imagery. This may be of considerable value in regional mineral exploration particularly in snow-covered terrains.

9.0 RECOMMENDATIONS

The investigators have had the opportunity to study snow enhancement under controlled condition, i.e. within the test areas, for only two images separated in time (December 2 and February 12). Useful results and information have been obtained through the analysis of this data. However, opportunities to monitor snow melt and thus more completely determine the role of differential melting in geological snow enhancement have been limited. In particular, the lack of snowfall within the Maryland-Virginia area has reduced the anticipated effectiveness and information yield of ground observations.

The investigators recommend that an extension in time be granted through next winter. The extension is justified on the basis of the following factors:

- The lack of snow cover within the Maryland-Virginia Test Area eliminated the possibility for collecting comparable geological data in an area of deep residual clay soils[1/] where fracture data is particularly needed and especially difficult to acquire[2/]. The opportunity to investigate snow enhanced phenomena directly within the field and to monitor snow melt and accumulation patterns in an area of deep residual soil was a primary reason for selection of this test area (Table 4).

- Observations of dynamic melt phenomena could not be made within the New England test area due to the transient nature of snow melt. An extension through next winter should provide the opportunity for direct field observation of snow accumulation and melt patterns within the Maryland-Virginia Test Area and provide a better and necessary understanding of the enhancement capabilities of snow cover.

- A comparison of the utility of the technique in areas of relative permeable soils (Massachusetts) versus areas of deep residual soil (Maryland) could not be conducted. Bedrock fracture data is difficult to acquire in such areas and techniques which contribute to developing such data are badly needed.

- EarthSat's Maryland-Virginia Snow Depth Reporting Network has been functionally operating (periodically reporting no snow) and could be re-established next winter at practically no additional cost.

- The lack of deep snow cover (e.g. >10 inches) within the New England Test Area hindered determination of assessments of the feasibility for extending snow enhancement techniques from temperate

---

[1/] Massachusetts has deep, sandy, glacial, transported soils.

[2/] A good example is the difficulty of acquiring subsurface fracture data for Washington METRO excavation in the suburban Maryland-Virginia area.

areas to areas of permanent snow cover. Geological data acquisition techniques within northern latitudes have often been ineffective[3].

Funds permitting extension of snow enhancement techniques through another winter (1973-1974) have been requested for the New England and the Maryland-Virginia test areas.

---

[3] The investigators have received and responded to numerous inquiries from foreign countries (e.g. Canada and Norway) on the use and limits of the techniques. Sequential studies of geological data yield within areas of heavy snow cover could provide a useful tool for photogeological reconnaissance and data acquisition in areas of long-term snow cover.

TABLE 4: TEST AREA COMPARISON MATRIX[1/]

GENERAL CHARACTERISTIC		NEW ENGLAND TEST AREA	MARYLAND-VIRGINIA TEST AREA
Regional Bedrock Geology		Triassic sediments and intrusives — schists, gneisses and marbles intruded by granitic and alkalic rocks	Triassic sediments and intrusives — schists, gneisses, and marbles intruded by granitic and alkalic rocks
Structure		regional strike N20E-many regional normal and thrust faults	regional strike N30E-no major thrusts known-some large normal faults
Landforms		till plains, kettle-kame moraines, drumlins, large alluvial flood plains and terraces	small alluvial floodplains and terraces, deeply weathered piedmont plain, subdued ridge and valley
Relief		0-2000 feet	0-1000 feet
Surficial Cover		glacial till, morainal deposits, glacial outwash	saprolitic residual soils
Soil Texture		medium-coarse (sandy)	fine-medium (clayey)
Native Vegetative Cover		deciduous and coniferous	predominantly deciduous
Snowfall	Mean Annual	32-64 in.	8-32 in.
	Annual Days	10-20 days	5-10 days

1/ Descriptive terms reflect broad characteristics of the area.

APPENDICES

APPENDIX A

APPENDIX A

May 20, 1973

PROGRESS REPORT SUMMARY

Reporting Period: October 31, 1972 - April 30, 1973

CATEGORY: 8-Interpretation Techniques Development

SUB-CATEGORY: C-General

TITLE: Facilitating the Exploitation of ERTS-Imagery Using Snow Enhancement Techniques - SR #141: NAS5-21744

PRINCIPAL INVESTIGATOR: Dr. Frank J. Wobber (P511)

CO-INVESTIGATOR: Mr. Kenneth R. Martin

SUMMARY:

Snow cover in combination with low angle solar illumination has been found to provide increased tonal contrast of surface features and is useful in the detection of bedrock fractures. Identical fracture systems were not as readily detectable in the fall due to the lack of a contrasting surface medium (snow) and a relatively high sun angle. Low angle solar illumination emphasizes topographic expressions not as apparent on imagery acquired with a higher sun angle.

A strong correlation exists between the major fracture-lineament directions interpreted from multi-sensor imagery (including snow-free and snow-cover ERTS) and the strike of bedrock joints recorded in the field indicating the structural origin of interpreted lineaments.

Viewing techniques (e.g., additive color presentations, density slicing, use of film snadwich and Ronchi grating) currently being tested promise to supply additional enhancement to the natural enhancement provided by snow cover and low angle solar illumination. In particular, additive color has contributed information related to fracture-influenced vegetative alignments.

A fracture-annotated ERTS-1 photo base map (1:250,000 scale) is being prepared for western Massachusetts. The map will document the utilization of ERTS imagery for geological analysis in comparative snow-free and snow-covered terrain.

APPENDIX B

APPENDIX B

TASK STATUS REPORT

TASK		STATUS	COMMENTS
PHASE I			
1.0	Establish Technical Interface with NDPF	Completed 6/30/72	Meetings held with the scientific monitor: ERTS-simulation U-2 aircraft imagery analyzed.
2.0	Assemble Geological Maps and Snow Cover Data	Completed 10/31/72	Subscription to New England Climatological Data: State geological maps of Massachusetts, Connecticut, Vermont, New Hampshire, and geological quadrangle maps for western Massachusetts purchased and analyzed.
3.0	Select and Establish Snow Points	Completed 2/28/73	A comprehensive net of weather stations has been organized. Physical ground points for light aircraft survey have been minimized.
4.0	Base Map & Underflight Preparation	Completed 10/31/72	Base map scale determined: Other New England investigators contacted.
5.0	Lineament Map Pre-Preparation	Completed 8/30/72	Radar imagery of Massachusetts, Connecticut, and Rhode Island was intensively analyzed to prepare geological lineament maps of the test area.
6.0	Snow Cover and Snow Melt Survey	Completed 12/31/72	Survey package designed and sent to newspapers in low density snow depth reporting areas. Readers indicating interest have been supplied with snow-depth reporting materials.
PHASE II			
1.0	Select & Analyze Snow Free ERTS Imagery	Completed 2/28/73	All ERTS-1 imagery of the test area analyzed upon receipt. Images 1096-15072-5 & 7 and 1096-15065-5 & 7 of the New England Test area and 1062-15190-5 & 7 of the Maryland Test area are being enlarged to a 1:250,000 scale to serve as a photo base map.

TASK	HEADING	STATUS	COMMENTS
2.0	Analyze Snow-Covered Imagery	Pending completion of ADP	All ERTS-1 imagery of the test area analyzed upon receipt. Intensive analysis of frames 1132-15074 & 1168-15065 has been conducted and is being compared with snow-free data. U-2 snow-covered imagery of the test area has also been analyzed.
3.0	Prepare & Submit A Preliminary Data Analysis Plan	Completed 12/31/72	A Data Analysis Plan has been submitted and approved by the ERTS Contracting Officer.
		PHASE III	
1.0	Modify Manual Optical & ADP Enhancement Techniques.	Completed 2/28/73	A re-evaluation of techniques and approach has been conducted. No major changes were necessary - minor modifications have been integrated.
2.0	Process ERTS Imagery Though Last Snow-Covered Period.	Underway	
3.0	Prepare Final Report	Underway	Sections of Final Report are being written as the experiment progresses. Sections I, II and III (Introduction, Background and Design) complete in draft form.
4.0	Prepare NDPF User Manual	Pending Completion of Final Report	

- Completed Tasks

APPENDIX C

GLOSSARY OF TERMS

Ablation--------------------------- Processes which reduce the depth of snow or ice cover including melting, sublimation and wind erosion.

Anticline--------------------------- A fold, the core of which contains stratigraphically older rocks; it is convex upward.

Anticlinorium----------------------- A composite anticlinal structure of regional extent, composed of lesser folds.

Berkshire massif-------------------- A massive topographic feature in the Berkshire mountain range consisting of metamorphosed igneous rocks more resistant than those of the surrounding rock strata.

Fault------------------------------- A fracture surface or zone in rock along which appreciable displacement has taken place.

Fold-------------------------------- A curve or bend of a planar structure such as rock strata, bedding planes, foliation or cleavage.

Foliation--------------------------- A general term for a planar arrangement of textural or structural features in any type of rock.

Fracture---------------------------- A surface along which loss of cohesion has taken place, i.e. a general term for any break in a rock including joints and faults. In this report the term is used to describe fracture traces (surficial expressions of subsurface fractures) as well as surficial fractures. The term is also utilized to describe linear fracture systems, i.e. series of fractures.

Glacial Drift----------------------- A general term for any material that has been transported by glaciers.

Glacial Striae — A series of long, usually straight and parallel furrows or lines inscribed on a bedrock surface by the gouge and scour of rock fragments embedded at the base of a moving glacier; usually oriented in the direction of ice movement.

Joint — A surface of actual fracture or parting in a rock without displacement of either side relative to the other.

Lineament — An alignment of natural features on a regional scale judged to reflect geologic structure. In this report the term is generally used to indicate what are unconfirmed expressions of joints, faults, fractures, foliation or bedding.

Metamorphic Rock — Rock that has formed under conditions of high temperature and pressure, having an interlocking arrangement of mineral grains known as crystalline texture. Chemical rearrangements and changes in shapes of mineral grains have occurred without actual melting of the rock from which they formed. Metamorphic rocks commonly have mineral grains arranged parallel to each other. Examples include slate, schist, gneiss, marble and amphibolite.

Snow Dusting — A very light, layer of snow cover.

Snow Enhancement — The accentuation of various phenomena on the Earth's surface resulting from the differential accumulation and/or melting of snow cover, or its obscuration by vegetative cover.

Snow Obscuration — The masking of underlying snow cover from aerial sensors by varying densities of vegetative overstory.

Taconic Orogeny — A major period of late Ordovician tectonic activity in the Northern Appalachian mountains during which the rocks making up the Taconic mountains were thrust westward to their present position.

Test Area--------------------------- Regional areas (e.g. Southern New England) which are analyzed to develop and refine a given hypothesis or technique.

Test Sites-------------------------- Localized areas of high geological interest within the test areas which receive intensive analysis.

Thrust Fault------------------------ A fault with a dip of 45° or less in which the hanging wall appears to have moved upward relative to the footwall, characteristically with a horizontal compression rather than a vertical displacement.

Validation-------------------------- A deductive system for giving increasing weight to a lineament using manual and/or electro-optical techniques.

APPENDIX D

APPENDIX D

ERTS IMAGE DESCRIPTOR FORM
(See Instructions on Back)

NDPF USE ONLY
D
N
ID

DATE May 22, 1973

PRINCIPAL INVESTIGATOR Frank J. Wobber

GSFC

ORGANIZATION EarthSat

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* LAKE	RIVER	SNOW	DESCRIPTORS
1205-15132-4	X	X	X	Syncline
1205-15132-5	X	X	X	Trush fault
1205-15132-6	X	X	X	Dendritic drainage
1205-15132-7	X	X	X	Geofracture
				Bedding
				Monoclinal valley
				Lineament
				Mountains
				Valley
				Massif
1204-15072-4	X	X	X	Valley
1204-15072-6	X	X	X	Mountain
1204-15072-7	X	X	X	Geofracture
				Lineament
				Massif
				Dendritic drainage
				Thrust fault
				(30% cloud-covered)

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

ERTS IMAGE DESCRIPTOR FORM
(See Instructions on Back)

NDPF USE ONLY
D
N
ID

DATE May 22, 1973

PRINCIPAL INVESTIGATOR Frank J. Wobber

GSFC

ORGANIZATION EarthSat

PRODUCT ID (INCLUDE BAND AND PRODUCT)	FREQUENTLY USED DESCRIPTORS* River	City	Coastline	DESCRIPTORS
1186-15075-4	X	X	X	Coastal Plain
1186-15075-5	X	X	X	Geofracture
1186-15075-6	X	X	X	Lineament
1186-15075-7	X	X	X	Basin
1204-15074-4	X	X	X	Snow
1204-15074-6	X	X	X	Geofracture
				Lineament
				Basin
				Mountain
				Dike
				Thrust fault
				Normal fault
				Bedding

*FOR DESCRIPTORS WHICH WILL OCCUR FREQUENTLY, WRITE THE DESCRIPTOR TERMS IN THESE COLUMN HEADING SPACES NOW AND USE A CHECK (✓) MARK IN THE APPROPRIATE PRODUCT ID LINES. (FOR OTHER DESCRIPTORS, WRITE THE TERM UNDER THE DESCRIPTORS COLUMN).

MAIL TO ERTS USER SERVICES
CODE 563
BLDG 23 ROOM E413
NASA GSFC
GREENBELT, MD. 20771
301-982-5406

GSFC 37-2 (7/72)

APPENDIX E

APPENDIX E

Snow cover for accentuating geological fracture systems—a new photogeological technique

By **Frank J. Wobber**
and **Kenneth Martin***

Figure below is an Apollo-9 color infrared (CIR) photograph taken at an altitude of 125 nautical miles over the Globe, Arizona, United States, area on March 12, 1969. The approximate photographic scale (1:1,000,000) and level of detail are comparable to imagery anticipated from the Earth Resources Technology Satellite (ERTS-A). Geographic reference points shown on the photograph include the town of Globe, Arizona (G), the Superstition Mountains (M), Theodore Roosevelt Lake (TL) and San Carlos Lake (SL).

The photograph demonstrates the value of snow cover as an enhancement technique for detecting fractures and other features (note circular feature, lower right) of possible interest to the mineral exploration community. Analysis of this and small scale aerial photographs indicate that snow cover (and probably the monitoring of snow melting) enhances subtle topographically expressed lineaments as well as fracture traces. Fracture traces are the surface expression of fractures covered by weakly consolidated sediments or soils. Fracture traces are photographically expressed as bare ground areas (dark photographic tones) which starkly contrast with the white tones of surrounding snow-covered areas. The detectability of subtle lineaments is reduced because this tonal contrast is not evidenced in snow-free areas.

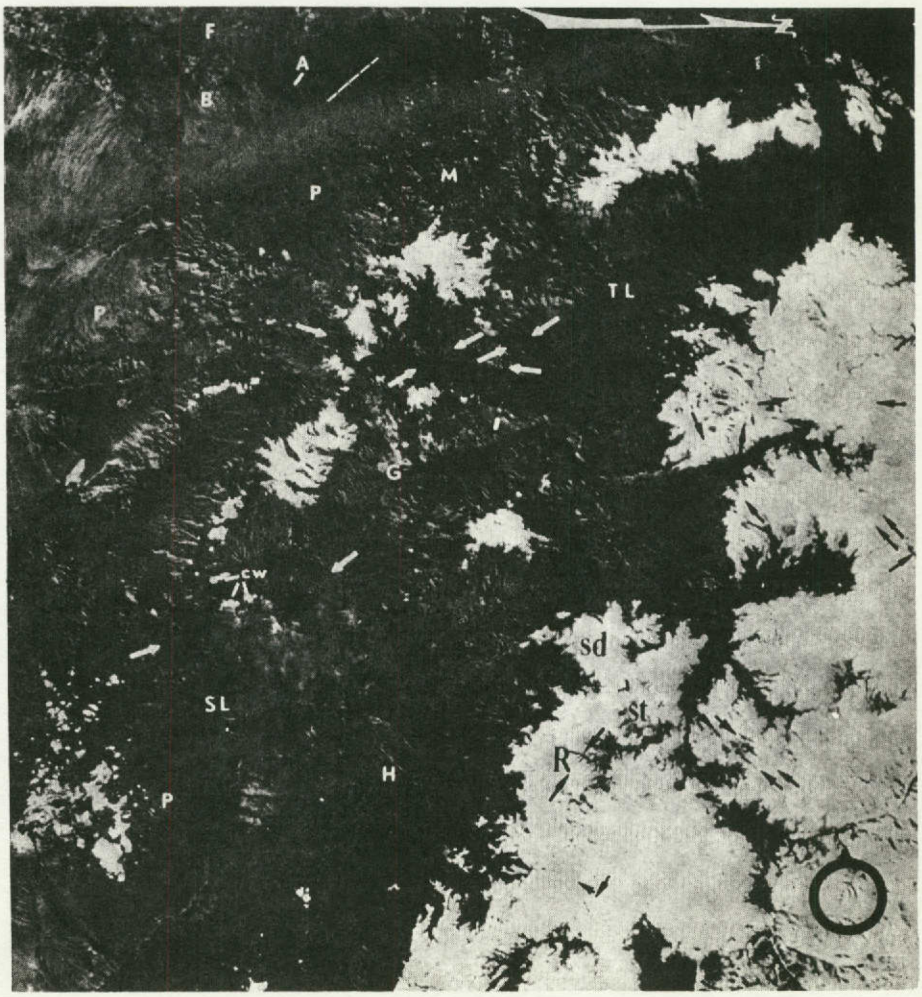
Within the snow-covered area, selected lineaments, which appear to be fracture traces or faults, have been mapped (black arrows). These lineaments are easier to detect within the snow-covered compared to the snow-free area. The primary cause for this enhancement effect appears to be variations in melting rates which occur over materials of different lithology and/or permeability. Fractures and faults generally have higher permeabilities than surrounding areas and can store moisture and raise their heat capacity so that freezing does not occur as quickly. New snowfall therefore melts off rapidly.

A comparative interpretative effort in snow-free versus snow-covered areas (white arrow) was conducted to identify significant lineaments. Fewer numbers of detectable lineaments were identified in snow-free areas assuming similar lithologies. This suggests that snow enhancement is a valuable tool in fracture detection and analysis. Not all lineaments detectable in snow-covered or snow-free areas are geological in origin. Manmade structures (e.g., transmission lines, pipelines, highways, railroads, etc.) may be confused with natural lineaments in analysis of small scale imagery. One such lineament (dashed line) which appears in the upper left of the photograph is a multiple lane-divided highway, U.S. 80-89. In close proximity to the highway are the checkerboard field patterns of irrigated croplands (F) near the Gila River. A thinly veneered pediment (P) grades into an alluvial apron or bajada (B) formed by coalescing alluvial fans. Other pediments and bajadas occur and can be identified from the photograph.

The problem of distinguishing snow cover from cloud cover is well exemplified in several areas on the photograph. Small areas of snow cover(s) could be difficult to differentiate from singular or wispy cloud formations. Cloud formations, however, are distinguishable in that they tend to obscure surface detail, cast noticeable shadows, and often have unique texture and form.

Tonal variations within snow covered areas suggest differences in snow depth, which may be a function of topographic obstructions, wind direction, solar aspect, or other factors

Continued on page 89



* Wobber and Martin are with the Geosciences and Environmental Applications Division, Earth Satellite Corporation, 1771 N. Street N. W., Washington, D. C., United States

APPENDIX F

BIBLIOGRAPHY

Bain, G. W., 1941,"The Holyoke Range and Connecticut Valley Structure" Am. Jour. Sc Vol. 239, No. 4.

Barnes, J. C. and C.J. Bowley, 1969,"Satellite Surveillance of Mountain Snow in the Western United States", Final Report prepared for Department of Commerce, Environmental Science Services Administration.

Barton, R.R., 1962,"Differential Isostatic Rebound - Possible Mechanism for Fault Reflection through Glacial Drift": A.A.P.G. Bull., Vol. 46 No. 12.

Blanchet, P.H., 1957,"Development of Fracture Analysis as Exploration Method", Bull. Amer. Assoc. Petrol. Geol., Vol. 41, No. 8.

Bromfield, Calvin, S., Eaton, Gordon P., Peterson, Donald L., and Rattle, James C. 1972. "Geological and Geophysical Investigations of an Apollo 9 Anomaly near Point of Pines, Arizona." USGS open file paper. 19pp.

Cohee, G. V. et al 1962, Tectonic Map of the United States: A.A.P.G. - U.S. Geological Survey.

Delwig, Louis F., MacDonald, H.C., and Kirk, Jan N. 1970. "Technique for Producing a Pseudo Three-Dimensional Effect with Monoscopic Radar Imagery" Photogrammetric Engineering. Vol. 36, No. 9, pp. 987-988.

Doll, C. G., 1961, Centennial Geologic Map of Vermont: Vermont Geological Survey.

Eardley, A. J., 1962. Structural Geology of North America. Second Edition. Harper and Row, Publishers, New York.

Emerson, B.K., 1916. Preliminary Geologic Map of Massachusetts and Rhode Island. U.S. Geological Survey Bull. 597, Scale, 1:250,000.

Farquhar, O.C., Editor, 1967. Economic Geology in Massachusetts. Proceedings of a Conference in January, 1966. Published by the University of Massachusetts Graduate School.

Fisher, D. W., et al, 1960, Geologic Map of New York: New York State Museum and Science Map and Chart Series No. 15.

Flint, R.F., 1967. Glacial and Pleistocene Geology. John Wiley and Sons, Inc., New York.

Goldsmith, R., and Page, L.R., 1972 Annual Report -"Progress and Status of the Cooperative Geologic Program for the Massachusetts Department of Public Works." U.S. Geological Survey, Boston, Massachusetts.

Haman, P. J., 1964,"Geomechanics Applied to Fracture Analysis on Aerial Photographs": West Canadian Research Publ., Series 2, No. 2.

Hamilton, Warren 1971. "Recognition on Space Photographs of Structural Elements of Baja, California." USGS Professional Paper 718. 26pp.

Harwood, D.S., 1972, "Tectonic Events in the Southwestern Part of the Berkshire Anticlinorium, Mass. and Conn." GSA. Abstracts with Programs, Vol. 4, No. 1.

Hatch, N.L., 1972, "Tectonic History of Part of the East Limb of the Berkshire Anticlinorium, Mass.," GSA Abstracts with Programs, Vol. 4, No. 1.

Lattman, L.H., 1958, "Technique of Mapping Geologic Fracture Traces and Lineaments on Aerial Photographs": Photogrammetric Engineering, Vol. 24, No. 9.

Lattman, L.H., and Matzke, R.H., 1961, "Geological Significance of Fracture Traces": Photogrammetric Engineering. Vol. 27, No. 6.

Lowman, P. 1967. "Geologic Applications of Orbital Photography" NASA Technical Note D-4155. Goddard Space Flight Center. 25pp.

Lowman P. and Tiedemann, H.A. 1970. "Terrain Photography from Gemini Space Flight Center", Report X-644-71-15. 75pp.

Lutton, R.J., 1961, "Systematic Mapping of Fracture Morphology." G.S.A. Bul. Vol. 45, No. 2.

Lyon, R.J.P., Mercado, Jose, and Campbell, R. 1970. "Pseudo-Radar." Photogrammetric Engineering. Vol. 36, No. 12, pp. 1257-1261.

Mollard, J.D., 1959 "Photogeophysics: Its Application in Petroleum Exploration Over the Glaciated Plains of Western Canada": North Dakota Geol. Soc. 2nd Williston Basin Synposium, August 1959.

Morgan, B.A., 1972, Metamorphic Map of the Appalachians: U.S. Geol. Survey. Misc. Geol. Inv. Map I-724.

Nicks, Oran W., Ed. 1970. This Island Earth. NASA SP-250. Office of Technology Utilization, Washington, D.C. 182pp.

Page, L.R., 1969 "Geologic Analysis of the X-Band Radar Mosaics of Massachusetts" Second Annual E.R.A.P. Status Review, Vol. I. NASA, Manned Spacecraft Center, Houston, Texas.

Pohn, H.A., 1969, "Analysis of Images and Photographs by a Ronchi Grating." NASA Progress Report of Investigation.

Pressman, A.E., 1963, "Analysis of Airphoto Linear Patterns in Eastern Massachusetts": Photogrammetric Engineering. Vol. 29, No. 1.

Ratcliffe, N.M., 1972, "Revised Polyphase Structural Chronology in Western Massachusetts and Problems of Regional Correlation": GSA Abstracts with Programs, Vol. 4, No. 1 P. 40.

Robinson, Peter, 1967. "Progress of Bedrock Geologic Mapping in West Central Massachusetts." In Farquhar, O.C. ed., Economic Geology in Massachusetts.

Rodgers, John et. al., 1959. "Preliminary Geological Map of Connecticut and Explanatory Text." Connecticut State Geological and Natural History Survey Bull. 84.

Romey, W.D., 1971, Field Guide to Plutonic and Metamorphic Rocks, ESCP Pamphlet Series PS-5: Houghton Mefflin Co., Boston.

Sabatini, Romeo R., Rabchevsky, George A., Sissala, John E. 1971. Nimbus Earth Resources Observations. Technical Report No. 2, Contract No. NAS 5-21617. 256pp.

Trainer, F.W., 1967, "Measurement of the Abundance of Fracture Traces on Aerial Photographs": U.S. Geol. Survey Prof. Paper 575-C.

U.S. Geological Survey. 1972. "Space View of Alaska Reveals Hidden Faults". Department of Interior News Release; June 9, 1972.

Weller, Roger N. 1970. "Photo Enhancement by Film Sandwiches." Photogrammetric Engineering. Vol. 36, No. 5, pp. 468-474.

Wing, R.S. et al., 1970, "Radar Lineament Analysis, Burning Springs Area, West Virginia-An Aid in the Definition of Appalachian Plateau Thrusts," GSA Bull. Vol. 81, No. 11.

Wobber, F.J., 1967, "Fracture Traces in Illinois": Photogrammetric Engineering Vol. 33 No. 5.

Wobber, F. J. 1969. "Environmental Studies Using Orbital Photography." Photogrammetria (Special Volume). Vol. 24, No. 3-4, pp. 107-165.

Wobber, F. J. 1972. "The Use of Orbital Photography for Earth Resources Satellite Mission Planning." Photogrammetria. Vol. 28, pp. 35-59.

Wobber, F.J. and Martin, K.R. 1972. "Exploitation of Aircraft and Satellite Imagery Using Snow Enhancement Techniques." Presented to the International Geological Congress, Montreal, Canada. August, 1972.

Wobber, F.J., & Martin, K. R., 1972. "Utilizing Snow Cover For Accentuating Geological Fracture Systems. A New Photogeological Technique," World Mining. Vol. 25, No. 12. p55-89.

Woloshin, A. 1965. "Notes on Geologic Interpretation of Nimbus AVCS Image of Southern California." In Multisensor Imagery Collection, U.S. Army Corps of Engineers for NASA Earth Resources Survey Program, pp. 189-191.

Zietz, Isidore, et al, 1972, Northeastern United States Regional Aeromagnetic Maps: U.S. Geological Survey open-file report, scale 1:250,000.

Zietz, Isidore, and Zen, E-an, 1973, Northern Appalachians Penrose Conference. Geotimes, February, Vol. 18 No. 2.